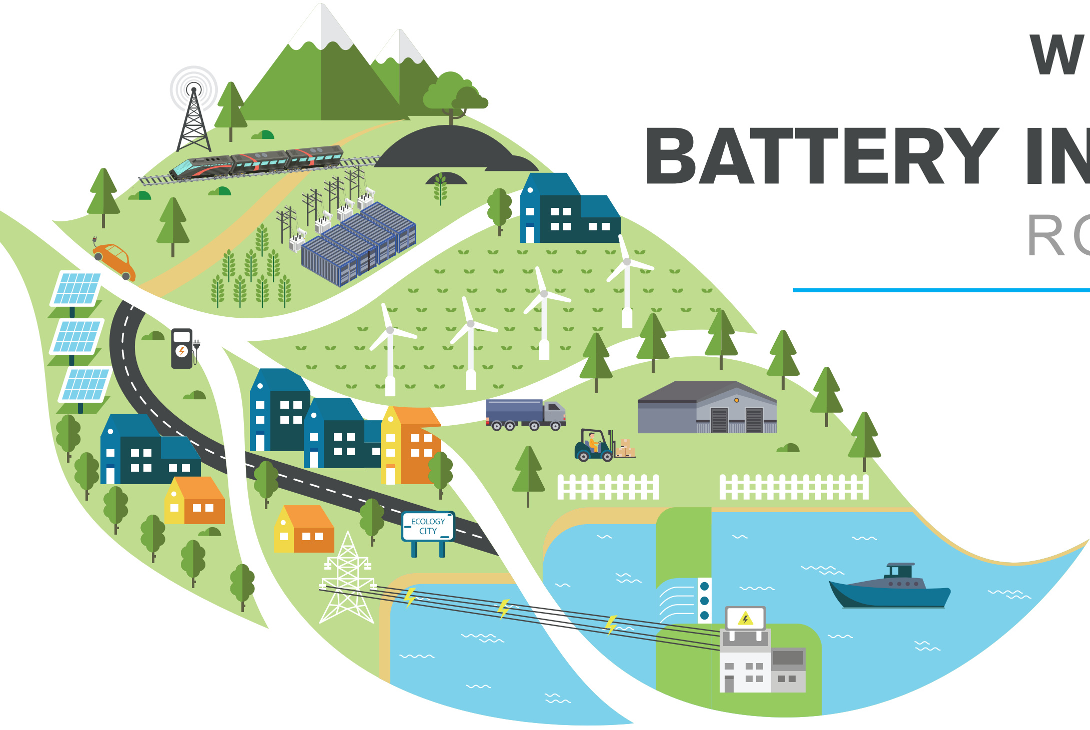
EUROBAT

ASSOCIATION OF EUROPEAN AUTOMOTIVE AND INDUSTRIAL BATTERY MANUFACTURERS

WHITE PAPER

BATTERY INNOVATION

ROADMAP 2030



EUROBAT

2030

BATTERY INNOVATION

ROAD MAP

WHAT IS EUROBAT?

EUROBAT is the Association of European Automotive and Industrial Battery Manufacturers. Its 50-plus members comprise more than 90% of the automotive and industrial battery industry in Europe.

MORE THAN
30
battery manufacting plants

16
research centers

OVER
€6.5BN
annual turnover

MORE THAN
50
manufacturers and Associate members from across the value chain

APPLICATIONS

AUTOMOTIVE

Batteries contribute to the decarbonisation of the European transport sector - reducing CO_2 emissions via start/stop batteries and innovative solutions in xEVs

STATIONARY ENERGY

Batteries are indispensable for storing renewable stationary energy coming from solar and wind farms in on grid and off grid solutions.They also contribute to a more stable and reliable grid.

MOTIVE POWER

MATERIAL HANDLING

Batteries are a perfect fit for powering industrial vehicles such as forklifts and cranes, while also reducing noise and emissions.

MOTIVE POWER

OFF-ROAD TRANSPORTATION

Batteries are widely used in rail, marine and air transportation. The concepts of smart charging of road vehicles to support the energy system is also relevant for off-road because their wide deployment and large energy capacities

ALL BATTERY TECHNOLOGIES

EUROBAT represents the manufacturers of all four existing battery technologies: **Lead-, Lithium-, Nickel- and Sodium- based**. Each chemistry has its own advantages and is best suited for specific applications.

Pb
LEAD BASED
ADVANTAGES
Affordable, proven, safe and sustainable

Li
LITHIUM BASED
ADVANTAGES
High energy density, low weight

Ni
NICKEL BASED
ADVANTAGES
Long life, suitable in extreme conditions

Na
SODIUM BASED
ADVANTAGES
High energy density, low weight

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Executive Summary

Batteries play a crucial role in supporting the European Green Deal, presented in December 2019, and the transition towards a decarbonised society and climate-neutral economy by 2050. They are recognised as key enablers for decarbonisation in transport, energy, logistics, production and telecommunications, supporting the energy transition and contributing to the improvement of a multitude of applications.

The **European battery industry has led the way in battery innovation and standardisation for many years, channelling** the European voice into global discussions and resulting in reliable products and quality standards tailored for a multitude of applications – **there is no one-size-fits-all battery.** Europe's battery sector takes a market-oriented approach, which anticipates shifting demand from continuous innovation in automotive, motive and stationary storage applications. It has **the experience and expertise to meet future demand** across many applications and has continued to tailor, and significantly improve, its products and maintain the flexibility to serve current markets and future demand.

The innovation and further development of electrochemical storage systems is an ongoing process that is based on the increased requirements of different applications. For the mainstream technologies discussed in this White Paper, a clear development roadmap exists.

In 2019, automotive and industrial lead batteries constituted 75% of the global B2B battery market. Different sources predict that this market will grow to over €200bn by 2030, representing over 1,800GWh, which would be three times the 2019 market value[(3)]. Lithium-based batteries will continue to have the highest growth, but lead-based batteries will also grow incrementally over the next decade[(3)]. Lead and lithium will remain the mainstream technologies in 2030 with substantial market shares.

Lead and lithium, as well as nickel and sodium based batteries, have a developing potential and the European industry is prepared to increase its investment in innovation. All these battery chemistries and technologies will continue to be essential in our low-carbon future. Each battery technology still offers strong innovation potential and has a clear development margin, driven by applications**. No single battery chemistry or technology can meet all the challenges of end-user** demand in a multitude of applications, combining high power and energy density, long life, low cost, excellent safety and minimal environmental impact.

The innovation and further development of electrochemical storage systems is an ongoing process that is based on the increased requirements of different applications. For the mainstream technologies discussed in this White Paper, a clear development roadmap exists. In the case of the well-established technologies, mainly lead, nickel and, to a certain extent, sodium, improvements concerning service life performance and safety will be enabled by using innovative materials and cell components in the electrochemical system as well as applying advanced battery management systems. **The outstanding feature in this process is that these improvements will be tailored to particular applications.** Lithium based technologies came in later, with successful deployment of mass-produced standard cell types to serve different applications – a strategy driven by cost and energy density.

In order to meet future demand and requirements, we need a regulatory landscape that treats all battery technologies equally to promote and stimulate battery production in Europe. With a coherent and supportive regulatory framework that allows the industry to evolve and innovate in line with future demand, Europe's domestic battery industry has the potential to develop and position itself for the future, while also retaining its profitability in current markets and applications.

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[3] CBI/Avicenne study report 2019

2 Scope and purpose of the Roadmap

This “Battery Innovation Roadmap 2030” complements the EUROBAT “Election Manifesto 2019-2024” and provides the technical background to the innovation potential of the key battery technologies to support and guide policy-makers.

EUROBAT represents the EU’s automotive and industrial battery industries. Our membership includes manufacturers of all four existing battery technologies – lead, lithium, nickel and sodium based batteries – and comprises the whole EU battery manufacturing value chain, with factories and production plants across Europe. This Roadmap focuses on these technologies and highlights their innovation potential in relation to the applications they serve.

Batteries are specifically designed to be used in particular applications. As such, **this Roadmap emphasises the importance of considering each application independently when targeting battery research and development (R&D) to innovate our products**. The battery features and targets selected in the EU’s Strategic Energy Technology Plan (SET Plan) strongly focus on plug-in HEV/EV propulsion batteries and 2nd life electric vehicle (EV) battery use only, which resulted in R&D targeting the most suitable technologies for these application profiles. However, there are many other emerging battery markets, each of which can contribute to transforming the EU’s economy for a sustainable future and meeting Europe’s 2050 climate neutrality target.

Consequently, this Roadmap focuses on a **variety of critical applications, identifying the key battery performance** to improve in order to meet future requirements for the applications they will serve. It concludes with **a set of research and innovation objectives per application, demonstrating the necessity and complementarity of different battery technologies, which all have a role to play and offer significant potential for development**. The technical details of the report are in the **Technical Annex**.

3 Drivers for battery innovation and R&D innovation priority areas

The European battery industry has expertise in market-driven R&D. Besides regulation, **battery innovation has historically been driven primarily by developments in applications**. This explains the very wide range of specific battery products, sizes, technologies and chemistries that co-exist in the market. The industry has been strong in Europe for decades in serving both mass and niche markets by leading national and international standardisation and contributing innovative products in the development of a multitude of applications.

This Roadmap features battery developments in key applications that can make a significant contribution to Europe's decarbonisation. We present the current technical requirements and opportunities for each battery technology, as well as the key features and technologies for improving the battery performance in each application within the **2030 horizon.**

To demonstrate the development potential of current mainstream battery technologies, we selected key applications grouped around four areas: **automotive mobility, material handling and logistics, off-road transportation and stationary storage**. The list of applications is not exhaustive, and other key markets exist where battery R&D is strongly driven by innovation. This is particularly true for military and medical applications. The European battery industry, with its proven expertise, is adaptable to new products and developments, and is ready to provide future applications with a host of new features that may not even be imaginable today.

Area 1 Automotive Mobility

The road transport sector is responsible for 20% of the EU's total CO_2 emissions, but has a strong potential for decarbonisation, with batteries as key enablers for increasing the energy efficiency of vehicles (all drivetrains) and road transport infrastructure. EUROBAT takes an active role in the decarbonisation of the road transport sector through its membership of the European Green Vehicle Initiative Association (EGVIA) and the European Road Transport Research Advisory Council (ERTRAC). Consumer pressure and regulatory drivers are forcing changes in vehicle technology. Today, **there is a strong focus on electric vehicles, but there is wide potential for the role of batteries to evolve further.** The Worldwide Harmonised Light Duty Vehicles Test Procedure (WLTC) brought a shift to using real driving data to assess fuel consumption and emissions and **the main challenge for automotive batteries is to capture the car's kinetic energy for the different degrees of hybridisation and electrification, from start/stop to mild hybrid, plug-in hybrid and full electric vehicles.**

The different battery types should continue to co-exist as they all have the potential to contribute considerably, depending on the application. Besides plug-in hybrid electric vehicle (PHEV) propulsion, we present three other types of automotive applications in development. These applications **present a major opportunity for the European battery industry and can play a crucial role in helping to realise the Green Deal's net-zero emissions goal by 2050.**

Low voltage (LV) electrification already provides significant savings for overall fleet efficiency to reach the EU's intermediate decarbonisation goals and PHEV/EVs help reduce local emissions and downsize the combustion engine.

Low and high voltage (HV) electrification strategies drive different requirements to energy systems as shown in the following applications.

Auxiliary 12V Batteries

Auxiliary 12V batteries are used in automotive vehicles, in internal combustion engines (ICEs) and at all levels of hybridisation. From micro, mild, full and plug-in hybrids to electric cars, the battery's main function is to support the 12V loads and to ensure the quality of the on-board net, as well as to ensure the safety manoeuvrings in case of emergency. Furthermore, start-stop functionality, cyclability and cranking are tailored to the specific vehicle architecture, although the cranking feature might disappear in the future.

The further market penetration of micro, mild, full and plug-in electric vehicles will not impact the 12V auxiliary battery market in the next 10 years as they are all already equipped with these batteries.

The dominant battery technology today is lead. Together with lead, lithium can also compete in this category to fulfil future requirements, as detailed in the Technical Annex.

Lead and lithium technologies are complementary in terms of performance, recycling and cost. For auxiliary applications, lead batteries are advantageous for their high temperature life, low temperature performance, recycling efficiency and cost, but could improve in terms of cycle life and energy density. The advantage of Li-ion batteries, however, is in their energy and power densities and cycle life at ambient temperatures. However, high cost, safety and recyclability, as well as extreme temperature performances, must be improved in order to become competitive with lead batteries.

Enhanced flooded (EFB) and absorbent glass mat technology (AGM), will generally be preferred. For lithium-based batteries, lithium iron phosphate (LFP) and lithium titanate oxide (LTO) will be the chemistries of use for such applications.

Start-Light-Ignition 12V batteries

© Clarios

Micro and mild-hybrid vehicles run with a 12V lead starter battery because of the battery's cranking function. Today, the worldwide SLI battery market is greater than 300GWh/year and is predicted to increase incrementally to over 500GWh/year by 2030[(1)]. Lead will continue to dominate this market because of its specific features, as outlined in the Technical Annex, and only a moderate penetration of lithium of 1-2% is predicted by 2030[(1)]. In the lead battery market, flooded batteries will retain a substantial market share, although enhanced flooded (EFB) and absorbent glass mat technology (AGM) will have a growing share.

Opportunity charging to capture the kinetic energy of the car will be key to improving energy efficiency. High voltage (HV) and low voltage (LV) Li-ion systems are developing further, but lead can also support the capture of excess energy. 'Dynamic charge acceptance' is a key innovation for batteries in such applications.

With **an increasing number of micro and mild hybrid vehicles on the road and the replacement market to serve for many years after, this application is a key enabler for Europe to meet its CO_2 reduction targets.**

The **European battery industry is currently a leader in the worldwide market**, as well as in the standardisation process with the International Electrotechnical Commission (IEC), and already has Giga- manufacturing capacities – approximately 60GWh at present.

[1] EUROBAT internal best estimates

Heavy Commercial Vehicle

In many cities today, trucks cannot run in idle overnight when charging or discharging, and in some Member States further legislation is being developed that will not allow cars to stay in idle for longer than a few minutes. Legislative changes have led to new battery requirements and resulted in **a completely new market developing, in particular for Heavy Commercial Vehicle-stand-by batteries (HCV-stand-by batteries).**

The purpose of these batteries is to ensure a high energy supply when both the engine is not running and electric energy demand is high. This requires deep-cycle performance, which cannot be achieved with existing conventional starting or dual-purpose lead batteries. Today, only lead is in this new market, but in future lithium might also kick in. However, the temperature window and the total cost of ownership for lithium will be a challenge, suggesting only limited market penetration by 2030 and continued lead dominance in this application.

Battery Electric Vehicle propulsion batteries (EV batteries)

The current EV worldwide market is 3.3m units, which will rise to 27m units by 2030[(4)]. Market drivers include favourable governmental policies/subsidies, rising emissions concerns and the further development of the charging infrastructure, including bi-directional vehicle-to-grid systems (V2G) in order to support grid-functionalities.

The importance of the entire battery value chain is increasingly recognised and supported by the European Commission, with many initiatives under the European Battery Alliance (EBA), as well as the battery features and targets being directly introduced in the EU's SET Plan to target the application.

The technologies of choice are lithium-ion batteries with Nickel Manganese Cobalt Oxide (NMC) and Lithium Iron Phosphate (LFP). Lead technologies are not suitable for the propulsion of PHEV/EVs but they still have a role to play to maintain the quality of the on-board net and to ensure the safety functions of the main battery.

The challenge of the lithium propulsion battery today is still the high cost and limited range of the EVs compared to ICE-powered vehicles. Also, faster charging, combined with safety and security aspects, are still key performance indicators to target for innovation. To meet these challenges, the industry is seeking materials to increase the volumetric and gravimetric density, as well as to maintain the safety and security aspects of the batteries. NMC and solid state technology are targeted in this respect. Recycling rates are currently at 50%, but progress is expected by 2030 to make it more economically viable.

4 IEA Global EV report 2019

Area 2 | Material handling and logistics applications

Material handling

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Logistics is an important part of supply chain management. There are different vehicle categories and a wide variety of forklift types with distinct applications, features and benefits. These include order pickers, reach trucks, rider pallet trucks, narrow aisle forklifts, high-capacity forklifts and side-loaders, but also automated guided vehicles (AGVs) and state-of-the-art robotic forklifts.

Traction and semi-traction batteries for material handling, such as in forklift applications, is an older market in which lead batteries currently have around a 90% market share. Lithium is only in the early stages of starting to penetrate this market. The worldwide battery forklift market is rated at 32GWh, with around 8% annual growth. Pushed by noise and emissions legislation, battery forklifts are steadily replacing ICE-types, with the market predicted to reach 73GWh by 2030(1).

Lead is likely to remain dominant in this rising battery forklift market in 2030, with potentially up to 80% market share, compared to a 15-30% market share forecast for lithium(3). One advantage for lead is the need for a counterweight, especially for sit-down and high-reach forklifts. Another advantage is the fact that, in one-shift regimes or when using battery swap infrastructures on location, there is enough charging time available. Moreover, in operations with opportunity and fast charging, the advanced lead batteries of the future will also offer increased flexibility and higher availability.

Lithium has entered the market for smaller forklifts and shows advantages in multiple shift operations, which are more energy-demanding and where battery charging time is limited. This is because lithium is less affected by opportunity charging, thus offering an extra advantage for 24/7 machine use. In some applications and niche markets with intensive use, the total cost of ownership could become lower than for lead. However, lithium batteries still face issues such as cost, functional safety and high mass energy density.

Nickel-based batteries represent a smaller part of the market, but also have a crucial role to play as they are used in extreme temperature conditions, such as in drive-in freezers.

Automated Guided Vehicles (AGVs) and Automated Guided Carts (AGCs)

AGVs and AGCs provide a smooth connection between modern production and assembly lines and conventional means of transport. Different types of AGV are referred to as ‘industrial trucks’. The definition is important with regard to machinery regulations. These transport systems are characterised by the fact that they are suitable for lifting, stacking and storing loads on shelves, can pick up and unload automatically within a company’s premises without requiring direct human interaction, and generally use electric drives. AGV systems demand batteries designed for heavy duty that are also able to accept high loads. Long service life and economy in use are other key requirements for the energy storage system, therefore requiring long maintenance intervals to reduce the total cost of ownership.

[1] EUROBAT internal best estimates

3 CBI/Avicenne study report 2019

The robust nickel-based technology NiCd, with its broad operation temperature range (-40°C to 60°C) has traditionally been the choice for AGV applications in extreme environments, although lead-based batteries retain the largest share in today's AGV/AGC market.

Lithium, with high energy and power densities, is now entering the market to power AGVs and AGCs because of restricted battery compartments and higher currents due to the heavy loads, hence the need for increased volumetric energy density and cyclability, which are key performance indicators for innovation.

Area 3 | Off-road transportation

The electrification of mobility also positively impacts off-road battery markets due to growth in existing and/or emerging markets in a multitude of applications. The off-road markets are very diverse and, besides railway, marine and air transportation, also cover agriculture, wheelchairs, cleaning machinery, leisure vehicles, and golf carts, amongst others.

Railway batteries

Rail infrastructure is the most efficient transportation mode in Europe with regard to CO_2 emissions and safety. It is, therefore, of great importance that we develop higher performance batteries to support innovation in both vehicles and infrastructure to further increase the performance and energy efficiency of the system.

The railway segment is a very fast-growing market, driven by increasing populations and growing demand for rail transport around the world. Asia is highly active in this sector and expected to have a significant impact on the train battery market in Europe. The overall battery market has high growth potential, with annual growth until 2025 forecast to be 25%, 5% and 4%, respectively, for Li-ion, Nickel-Cadmium and lead. Lead and advanced lead batteries with increased cycle and service life and low temperature tolerance will be the main technology for commuter trains in 2025 with a market share of more than 35%[1].

Railway batteries are located in the rolling stock and infrastructure. The mainstream technologies used are nickel based, in particular NiCd, flooded and sealed lead, and lithium based batteries. For the rolling stock, we differentiate between 'city traffic' (suburban railway and underground trains), 'regional traffic' (railway passenger carriages) and 'long-distance traffic' (railcars with ICEs), where batteries are used so serve different applications, such as for lighting and emergency power supply, delivering auxiliary services and starting diesel engines. For railway standby applications, we differentiate between batteries for 'trackside line signaling', 'street traffic control', 'signal and control boxes and enclosures' and 'wayside energy storage'.

New upcoming applications for battery systems are the **hybridisation and electrification of rail power traction**, mainly for commuter and metro trains. The requisite high energy, power density and cyclability for such applications can be covered by lithium systems in particular, which are expected to be the fastest growing battery segment due to benefits such as being maintenance-free and having a longer lifetime. For batteries used to power auxiliary functions, as well as lights and fans in high speed and metro trains, the nickel-based chemistry is the preferred technology. In this sector, there is growing demand for batteries, especially driven by Far East Asian markets. **Due to development trends for on-board units with smaller footprints, weight restrictions and constant reliability needs, the future requirements for energy storage systems consist mainly of improvements to volumetric energy density, lifetime and operation temperature range.**

[1] EUROBAT internal best estimates

Marine batteries

The marine sector is a strong contributor to CO_2 emissions and pollution in Europe and worldwide. Batteries are enablers that contribute to the transformation of maritime fleets in oceans, seas and inland waters, as described in Waterborne's Strategic Research Agenda.

There is an **urgent need to electrify all forms of boat and marine transport, which is an opportunity for both lead and lithium batteries** as they can all contribute and have their place in these markets. Lithium, due to higher energy densities and cycle life, is well-suited to the needs of propulsion, while lead batteries are more suitable for on-board auxiliary services, to ensure the on-board safety and security functions and to crank the diesel engines.

For larger ships and ferries, there are different degrees of hybridisation of the powertrains. Some long-distance cruise ships have thermal engines that charge the batteries via generators to power the electric propulsion engines and reduce fuel consumption and emissions when running at full power for long periods, while they can also operate on pure electric mode during short periods, for example when entering sea ports. Batteries can also be used for feeding excessive loads (peak-shaving).

For the propulsion of smaller vessels, other hybrid electric systems are developing, including the integration of solar and wind energy. There are also full electric plug-in architectures developing with charging infrastructure at ports where on-board battery systems, once they are fully charged, allow vessels to run autonomously without any fuel consumption or emissions during use. Standardisation is a challenge to reduce costs and meet the high safety requirements of the systems that are used on-board.

For smaller boats, 48V propulsion batteries are used. To increase the propulsion power and range, the potential for innovation is in the gravimetric/volumetric energy density.

Area 4 | Stationary Energy Storage batteries

The European power system is undergoing major transformations requiring more flexibility and interconnectivity to optimise energy resources. Applications are at different levels of maturity, ranking from early demonstration to very mature deployment Battery Energy Storage, which has the potential to make an effective contribution to Europe's decarbonisation targets, energy security and independence. Batteries have the advantage of being tailored to specific functions and can be quickly installed on location. Innovations will focus on long service life, total cost of ownership, reliability, safety and conversion efficiency.

Because of this diversity, all battery technologies – lead, lithium, nickel and sodium – have an important role to play at each level of the grid: from generation and transmission to distribution and households, batteries will deliver important services, such as integration of renewables and grid stabilisation. Batteries can deliver flexibility for a climate-friendly, safe and reliable energy supply system, enabling the decentralisation of the system and integration of high proportions of renewable energies, as well as to support the charging infrastructure for high volumes of EVs. Energy storage systems are also central elements of sector coupling paths and provide the necessary flexibility to support key functions such as:

- **Voltage stabilisation in the medium and low voltage grid**
- **Ensuring global energy balance and frequency**
- **Preventing the grid from overload**
- **Balancing electric generation and demand from renewable energy sources**
- **Surplus energy management**

The stationary storage battery business is not restricted to grid-functionalities only, but also serves poor and off-grid energy systems. These markets, in which the European battery industry has a strong position, are global and growing year-on-year. The key stationary battery applications that we have selected for the report are Uninterrupted Power Supply (UPS), Telecom, 'Residential/Commercial storage behind the meter' and 'Utility grid-scale Energy Storage Systems at the level of power generators, transmission (TSO) and distribution (DSO) system operators'.

Figure: Stationary Energy Storage segmentations: ESS services generate 20 market segments[3]

		Regul-ation[1]	Arbitrage: Hourly/ daily peak	Arbitrage: Weekly peaks	Arbitrage: Seasonal peak	Black start	Back-up: UPS	Back-up: Power continuity	Back-up: Reserves	Invest. deferral	Grid independ-ent power supply
Gener-ation	Conventional & regular RE	1 ✓	4 ✓	✓	7 ✓	8 ✓			9 ✓		10 ✓
	PV integration	2 ✓	5 ✓	✓	✓						✓
	Wind integration	3 ✓	6 ✓	✓	✓						✓
Transmission & Distribution		11 ✓							12 ✓	✓	
End-users	Residential	13 ✓	14 ✓	✓				✓			19 ✓
	Commercial	✓	15 ✓	✓		16 ✓	17 ✓	18 ✓			
	Industrial	✓	✓	✓		✓	✓	✓			20 ✓

Existing markets # Emerging markets

Batteries for Uninterrupted Power Supply - UPS batteries

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UPS is an older market in which lead has been the dominant technology for decades and is expected to remain so by 2030. The total global market is expect to grow from 15GWh to 24GWh by 2030, which represents a 4% annual growth. This growth is due to increased use of big data and the associated need for new data storage centres. Lithium is expected to have a 7-18% market penetration by 2030[3]. Another driver will be the growth of emerging economies, requiring significant UPS capacity, with Europe as a leading battery supplier.

Batteries for UPS are cells or blocks connected to form a back-battery for uninterrupted power supply. A UPS battery provides instantaneous power to a system if the main power source fails. The voltage of the battery depends on the size of the UPS, which can range from the protection of single computers up to data centres or buildings. UPS is an existing market with new requirements developing.

3 CBI/Avicenne study report 2019

Key performance indicators for this application are energy and power densities, system costs, charge acceptance, energy throughput, operating temperature range and reduced cooling. Increases in the power density are required because of the further electrification of critical loads, which require more output from the battery. This affects both lead and lithium technologies. The UPS stand-by application is expected to extend its usage beyond uninterruptible power in order to generate more value, for example UPS and peak-shaving and UPS as reserve power (UPSaaR). An additional key performance indicator for UPS with such multiple functions will be the energy throughput.

Another development is the connection of smaller UPS batteries in one network to form a larger UPS system or even to form a virtual power plant (VPP). This will become possible thanks to the development of 5G and artificial intelligence to allow distributed energy production, storage and consumption. Such VPPs could include traditional commercial and industrial UPS batteries from data centres and base transceiver stations, but also batteries from EVs, forklifts, utility grid-scale and batteries behind-the-meter.

Because of these innovations, it will be necessary to work on the charge acceptance of the UPS batteries and their robustness to higher temperatures from faster charging. The extended usage will also require a considerable increase in energy throughput.

The technology of choice for the user is not only related to the type of load but also on the climate (temperature robustness), the quality of the grid and configuration of the UPS, as well as the energy throughput. Cost remains a key factor.

Telecom batteries

© Stanislas Verdonckt

The associated total worldwide battery market is currently rated at 17GWh, increasing to potentially 25GWh by 2030. Lead is currently the dominant technology, although the lithium market share is forecast to be 9-23% by 2030[1]. The market share of lithium, however, could be even higher, depending on battery raw material costs. This means that the lead market will remain stable for the next decade, with lithium absorbing the market increase.

Telecom batteries are cells or a blocks connected to form a 48V direct current (DC) energy storage system able to supply electricity to an information and communication technology or telecom site when the main power source is unavailable or insufficient.

Key performance indicators for this application are energy and power densities, system costs, energy throughput, charge acceptance, operational temperature range and recycling. In contrast to the UPS, telecom batteries will serve only telecoms applications. An important driver is the demand for increased energy throughput, in particular because of the rolling out of 5G networks.

1 EUROBAT internal best estimates

Residential and Commercial Storage batteries behind the meter

The residential and commercial sectors are responsible for 12% of the EU's total CO_2 emissions. More than 4GWh of additional capacity per annum is predicted by 2022[(4)], resulting not only from increased numbers of units sold but also because the increased demand for larger storage systems will increase self-consumption. The use of different electro-chemistries provides an overall benefit to the decarbonisation of the residential sector and batteries are key enablers for making this happen.

Stationary batteries for storing energy from renewable sources behind the meter are used both in residential and commercial buildings (offices, SMEs, etc.) where they can also fulfil additional roles, such as peak-shaving or UPS. Their primary task is to supply the load when electricity costs are high or renewable power output low. Drivers for residential and commercial storage batteries are increased self-consumption and the need to ensure power continuity. Another function, in combination, is as a dual battery for an EV home (fast) charging station.

Both lead and lithium can compete in this market, each with their own features. Lithium currently dominating this market[(6)] has advantages with regard to space, but safety to be further improved for in-house storage requirements, which necessitates a move to solid state technology. For lead, bipolar technology will increase the energy density and charge efficiencies.

Lead today is not only fully recyclable, but also has economies of scale in place that work without any subsidies. For lithium, there is still progress to be made for it to be economically viable by 2030. Design life needs to be improved for both technologies, as well as the cycle life.

Utility grid-scale Energy Storage batteries (ESS batteries)

Utility grid-scale energy storage for grid-functionalities is a market where batteries compete with other storage technologies, such as hydro-power and fuel cells. However, batteries have considerable advantages as they are easy to install on location and scalable to the power and capacity needs of the application. The opportunities for batteries are promising, and a global market of 60GWh and over €10bn sales is expected already by 2025[(1)].

Batteries can provide grid stability in multiple ways. They can store energy quickly or feed in, in milliseconds, for grid compensation to avoid frequency instability and compensate deviations caused by fluctuations in generation and load. Batteries also provide reserve capacity for the grid to take on the role of spinning reserves provided by conventional power plants. Battery energy storage is also required to restart after a complete power failure (black start) or to supply energy to an island power grid integrated with renewables. Due to their short response times, in the millisecond range, battery storage systems are suitable for providing control energy down to the minute range. The provision of control power from pooled, decentralised battery storage is already economical today.

The creation and use of local flexibilities to support the network is the key to optimising the use of distribution grid capacities.

4 IEA Global EV report 2019
6 IEA Tracking report 2019
1 EUROBAT internal best estimates

4

Environmental Performance of Batteries

EUROBAT supports cradle-to-grave lifecycle analyses in order to develop and promote sustainability, and the circular economy. Besides, industry is implementing and further developing sustainability practices in all phases of the battery product life. That is, during the production, transportation, manufacturing and use phases, as well as recycling an reuse.

At the end-of-life stage, virtually all batteries from the different applications that are available for collection are collected and processed for recycling. The **recycling efficiency levels in the Batteries Directive can be met independently of the application.**

The European battery industry is leading the process on battery standardisation with regard to performance, dimensions and safety, as well as the environmental performance of batteries (all technologies) within the framework of the International Electrotechnical Commission (IEC), TC21 and its SC21A, and the mirror group at European level, Cenelec, TC21x.

The industry has developed a standard colour code (IEC Standard 62902) to direct the waste stream from the different technologies on the market.

Lead-based batteries:

Pb

The collection and recycling industry is well established and ensures a minimum environmental impact. The EU has **a mature process of collection and recycling that is both efficient and cost-effective and operates within a well-established infrastructure**. Batteries are collected by specialist companies and recycled within specialised recycling facilities (secondary lead smelters) in a closed-loop system that operates under strict environmental regulations. From an end-of-life perspective, this process reduces the need to produce additional virgin materials, such as primary lead and plastics, which have the biggest environmental impact in the lifecycle of the product. Today ,an astonishing 99% of end-of-life lead batteries are collected and recycled because only the lead technologies recycling process generates net-income throughout the entire value chain.

Lithium-based batteries:

Li

Recycling is undertaken through either pyrometallurgy or hydrometallurgy, and some newly installed capacities are currently under development. End-of-life cells and modules, as well as production scraps, are not crushed but treated directly. **Valuable metals are recovered for conversion into active cathode materials for the production of new batteries**. Lithium represents a small fraction and is not currently reused.

Nickel-based batteries:

Ni

Partnerships between producers, logistics companies specialised in the transportation of hazardous waste and fully permitted EU-based recyclers ensure that **industrial end-users can dispose of their spent, industrial NiCd batteries in an easy manner.** This ensures proper recycling of used batteries, the reuse of their components to manufacture new batteries or other industrial goods and the protection of the environment in a closed loop.

5

Recommendations for the EU Battery Action Plan

Although lithium cell manufacturing for the propulsion of EVs in the EU is critical for serving future demand, hence the European Battery Alliance, the EU's Battery Action Plan should not be limited to one technology/application only as many battery technologies will contribute to meeting the zero-emissions goals of the Green Deal.

The situation of other application segments and the EU lead battery manufacturing industry is totally different, with well-established manufacturers and a supply chain already in place, having leading positions in a multitude of current and emerging markets with global players and employing thousands of workers in Europe. At the same time, certain technologies are already at a very advanced stage of development. The recycling processes for some are not yet installed at industrial scale and need support in order to improve. Work is still needed on the established technologies as the closed-loop and circular economy aspects for upcoming technologies are also not yet confirmed. All battery technologies must be positioned as future and innovative solutions, particularly lead.

Recommendations for key sustainability performance indicators for a thriving battery industry in Europe is an option that should be further developed, with a balanced legislative approach that supports all technologies and does not prioritise one over another.

EUROBAT recommends that future EU R&D public funding activities should be spread more equally among the different technologies by targeting applied research on different applications. Today, battery technologies are still competing or are complementary in different market segments and Europe will benefit if it leaves the door open for all technologies to be able to maximise their market innovations to meet the goals of the Green Deal.

EUROBAT is member of the WG2 ('Raw Materials and Recycling') of the ETIP 'BatteRIes Europe' and a supportive partner of the 'Batteries 2030+' initiative to follow up on the need for functional requirements in order to achieve the EU's zero-emissions goals. Together with private funded R&I initiatives, R&I proposed activities should help in playing this key role.

6

Concluding remarks

Europe must maintain a fair, level-playing field for all battery technologies as each of the complementary technologies will be needed to transform the EU into a fair and prosperous society with a modern, resource-efficient and competitive economy with net-zero emissions by 2050. Europe cannot afford to phase-out one battery technology in favour of another as they all contribute to the EU's decarbonisation targets.

The European battery industry, represented by EUROBAT, recognises the importance of developing all battery technologies in order to maximise our contribution to Europe's decarbonisation strategy. The European Commission states that "achieving a circular economy requires the full mobilisation of industry". Our industry stands ready and eager to play its part.

This study demonstrates that all battery technologies are complementary, with each having features and significant developmental potential that will support the Green Deal in delivering a climate neutral Europe by 2050.

Policy should move in the right direction to (1) treat all battery technologies equally by extending **the exemption of lead batteries in the End-of-Life Vehicle Directive (ELV)** and (2) **gather all pieces of legislation on the battery sector into one, single updated Batteries Directive.**

Europe must maintain a fair, level-playing field for all battery technologies as each of the complementary technologies will be needed to transform the EU into a fair and prosperous society with a modern, resource-efficient and competitive economy with net-zero emissions by 2050. Europe cannot afford to phase-out one battery technology in favour of another as they all contribute to the EU's decarbonisation targets.

Europe is diverse. Having different manufacturing technologies in our portfolio has strategic advantages, such as cutting the costs of raw and secondary materials and having self-sufficient sourcing and manufacturing. **Putting too much emphasis on one technology would be to take a tactical risk with Europe's competitiveness**. It would also reduce the buying power of European citizens, as well as lose our industrial knowledge in markets where we are currently strong. Instead, Europe can benefit from the strong position of the existing manufacturing industry, which has demonstrated incremental improvements over many years, resulting in very good circular economy business models that are beneficial and self-financing for all parties, ensuring all batteries are collected for recycling.

TECHNICAL ANNEX

Contents

1 Introduction

Market-driven R&D has resulted in a wide variety of commercial lead-, nickel-, lithium- and sodium based battery products that are available on the market today. **This large variety of products is the result of incremental improvements** introduced over many decades to fit the specific needs of the applications and their ever-increasing demands.

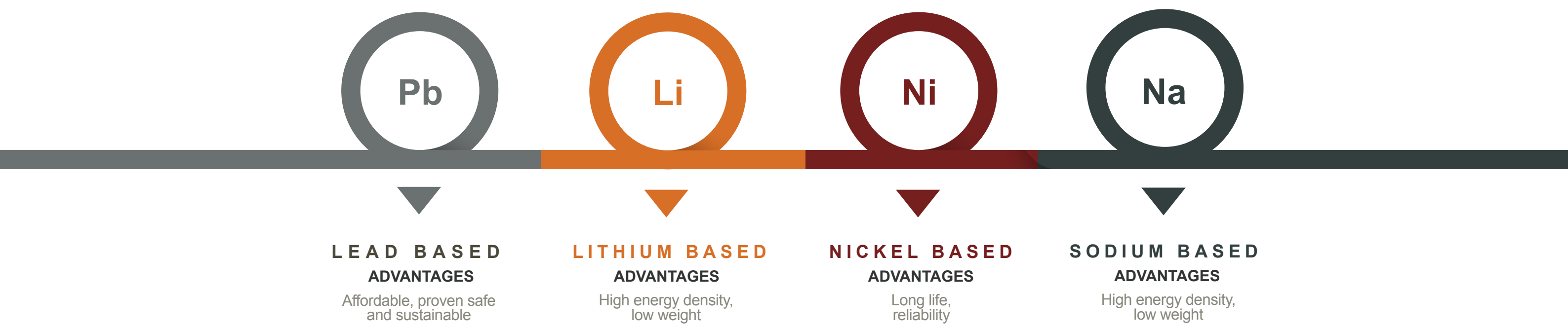
Leading on battery standardisation and with active production lines in service, the European battery industry has been keen to take these improvements from the lab to the market in order to launch new products to serve new demands and requirements. This explains why the European battery industry retains a leading position in the European lead based automotive and motive power markets and, to a lesser extent, in the stationary business[1].

This Technical Annex provides the technical background to the twelve applications that are examined in this White Paper. It demonstrates how the different battery technologies and chemistries each have their specific role and developmental potential in order to anticipate the shifting demand from the continuous innovation in automotive, motive and stationary storage applications.

This is not a scientific paper, but aims to provide a direction on current technical battery requirements and what we believe is feasible to target by 2030. With this market-oriented approach, battery experts have identified the key performance indicators per technology to prioritise R&D in order to meet the above-mentioned shifting demand.

The mainstream battery technologies considered in the White Paper are lead-based, including advanced lead technologies, lithium-based and nickel-based batteries. Sodium technologies also have the potential to improve, with R&D focused on improving the recharge power and increasing cycle life through design enhancements. However, such technologies cover a smaller segment and are, therefore, not included in this Roadmap. **This EUROBAT Roadmap aligns with the innovation roadmaps of the Consortium for Battery Innovation (CBI) and RECHARGE.**

BATTERY TECHNOLOGIES AND APPLICATIONS



1 EUROBAT internal best estimates

2

Overview of battery technologies

Lead based technologies

Pb

The lead battery has been the predominant energy storage device for the industrial and automotive markets for over 100 years. Different designs of lead-based batteries are available, with an important choice to be made between flooded or 'vented', requiring maintenance, or maintenance-free valve-regulated (VRLA) batteries. They can be connected in large battery arrangements without sophisticated management systems and are differentiated from the other technologies by a low cost per kWh installed and low cost per kWh electricity throughput.

It is often overlooked that the lead battery has continuously innovated in response to new requirements in terms of functionality, durability and cost. The recent mainstream introductions of absorptive glass-mat (AGM) batteries, enhanced flooded batteries (EFBs) battery monitoring sensors and battery management systems (BMS) are obvious examples of continuous improvement.

To compete with upcoming electrochemical storage technologies, there is a need to accelerate the pace of innovation. This could be through a better dynamic charge-acceptance at uncompromised high temperature durability or by improving the energy and power densities with improved cycle-life. Specific power could be improved by developing new advanced additives to decrease the internal resistance, while the cycle life could be lengthened through design enhancements such as corrosion-resistant lead-alloys. More intelligent battery operation modes could also be developed.

Apart from fundamental research to improve the electrolyte, materials and components used, other improvements can still be made. The use of innovative materials for components like synthetic expanders, nano-based carbon materials, new alloy compositions, improved thin plate pure lead (TPPL) and bipolar cell design will be key developments for lead-based technologies to further advance in view of future requirements in a multitude of applications.

Occupational exposure to lead is now under control because the battery industry has proactively taken measures to limit the exposure of its employees to blood lead contamination during the manufacturing process. Europe should allow the market to drive the change and recent progress on lead battery research should not be discounted. The further development of lead batteries in a variety of enhanced technologies will serve applications that can contribute to the achievement of the zero-emissions targets in the European Green Deal.

The Consortium for Battery Innovation issued in 2019 has also some intermediate short and medium-term targets defined by Key Performance Indicators which are closely aligned with these in the EUROBAT Innovation roadmap to meet new market needs in two key areas:

Key Performance Indicators and intermediate targets for Automotive start/Stop and micro-hybrid batteries

Indicator	2019	2022	2025
Dynamic charge acceptance, A/Ah	0.4	2.0	2.0
PSOC Cycle life (17.5% SoC)	1500	2000	3000
Water loss, g/Ah	3	3	3
Corrosion, test units to SAE J2801	12	18	22

Key Performance Indicators and intermediate targets for Industrial Stationary Energy Storage batteries

Indicator	2019	2022	2025
Service life, years	12+	12-15	15-20
PSOC Cycle life PV duty cycle	1500	2000	3500
Cycle life, 70% DOD	1000-3000	5000	6000
Charge efficiency, %	85-90	90-95	95

Lead based battery circular economy targets

Recycling targets for lead batteries will be maintained at a very high level in 2030, with efficiency over 90% and recycling of active materials at 99%, achieving a circular economy and benefiting the whole value chain by 2030.

Lithium based technologies

Li

Lithium-ion (Li-ion) is considered the leading lithium technology for automotive and industrial applications, and will remain so in 2030. Lithium is currently deployed in mass-produced standard cell types in different applications – a strategy driven by cost and safety reasons. The major requirement for higher energy densities to achieve increased driving range is directly linked to e-mobility. This results in a development roadmap for 2030 that mainly considers the lithium-based technologies based on modified Nickel Cobalt Manganese Oxide (NMC) materials, from NMC 111 to NMC 811, with increased nickel and reduced cobalt content in combination with high capacitive anode materials with carbon/silicon composites. Solid state technology should also be targeted to increase the energy density and improve the safety aspect.

The Li-ion technologies considered in this Roadmap consist of a combination of the following available anode and cathode materials.

SPECIFIC CAPACITY OF ANODE AND CATHODE MATERIALS:

Anode	- C:	350 – 360 mAh/g
	- Si(SiOX)/C:	400 – 900 mAh/g
	- LTO:	150 mAh/g
Cathode	- NMC 111:	160 mAh/g
	- NMC 532:	175 mAh/g
	- NMC 622:	180 mAh/g
	- NMC 811:	175 – 200 mAh/g
	- NCA:	200 mAh/g
	- LFP:	150 mAh/g
	- LMO:	105 – 120 mAh/g

GENERATIONS OF LITHIUM MATERIALS CONSIDERED FOR FURTHER DEVELOPMENT BY 2030:

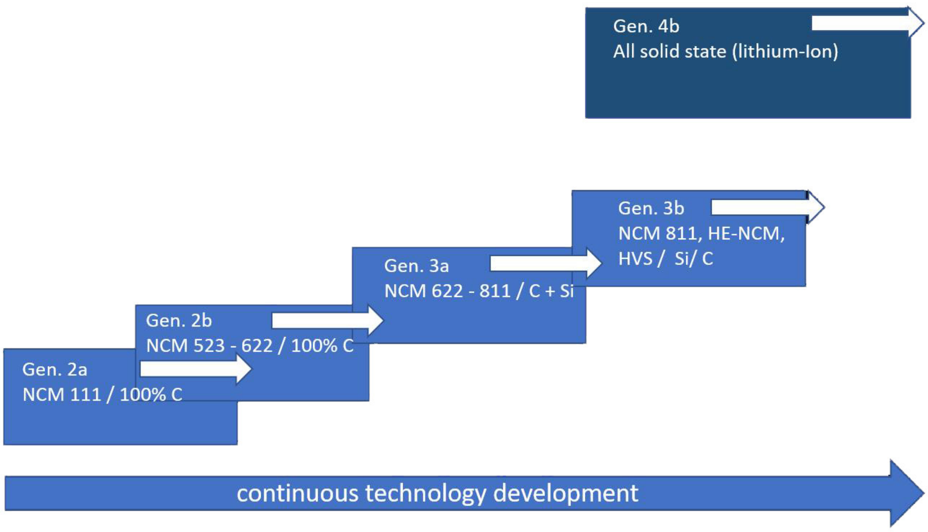


Fig. 1 Development roadmap for Lithium-Ion, Ni-rich NMC positive electrode and new materials for the negative electrode (e.g. Si/C composite).

- **Generation 2a.** NMC 111 / 100% C
- **Generation 2b:** NMC 523 -622 /100% C
- **Generation 3a:** NMC 622 / C+ Si (5-10%)
- **Generation 3b:** NMC 811 / Si/C composite

Due to the variety of possible combinations of cathode and anode materials, the resulting Li-ion batteries show specific and individual performance characteristics suitable for different kinds of applications. The development of Li-ion technologies suitable for industrial and automotive applications is still a challenge in terms of material research, process, production, development, recycling, safety and transportation.

REQUIREMENTS FOR CATHODE MATERIALS

- **High specific energy (mAh/g)**
- **Safety**
- **Stability (cycle and calendric)**
- **High voltage**
- **Low polarisation**
- **Low price**
- **Low content of rare materials (e.g. cobalt)**
- **Low CO_2 footprint at production**
- **Environmentally and ethically harmless**
- **Easy processing**
- **Availability**
- **High power capability**

ECONOMIC AND ENVIRONMENTAL REQUIREMENTS

- **Low price**
- **Low content of rare materials (e.g. cobalt)**
- **Easy processing**
- **Availability**
- **Environmentally safe and ethical**
- **Operationally safe**
- **Low CO_2 footprint during production**

CHALLENGES IDENTIFIED

- **Production processes**
- **Recycling processes**
- **Transportation**

Lithium based battery circular economy targets

Recycling targets for lithium batteries will be maintained at the current level of 50%, but active material recycling is expected to increase from 65% to reach 85% by 2030, to recover in future also nickel, cobalt and lithium to be fully commercially viable.

Nickel based technologies

Ni

Nickel-based batteries are the technology of choice for applications used in extreme climate, cycling or fast charging conditions. Different designs are available: pocket, sintered, plastic-bonded, nickel foam and fibre electrodes. Cells are prismatic or spiral wound, flooded (or 'vented') or valve regulated, the latter also being maintenance free.

Thanks to decades of safe use under the most extreme operating conditions and continuous development, nickel-cadmium is mostly used in special and niche applications.

Using innovative materials, this technology can be further developed for existing applications and as a replacement solution with its key performance properties in extreme conditions having the potential for further improvement. Nickel-based batteries are among the electrochemical storage systems that should be considered for industrial applications over the next decade.

Nickel based battery circular economy targets

Recycling efficiency should increase from the current 79% (active materials at 50%) to 80-85% (active materials at 55-60%) by 2030 to reach a break-even business model.

3

Overview of Battery Performance features and targets per technology

The tabulation hereunder provides the state-of-the-art performance data and 2030 targets for each battery technology. The table presents the capability and innovation potential of each technology, independent of the application for which they are designed. The large range that is given for each parameter is due to the fact that a variety of battery technology products serve the different applications in the market, of which twelve are analysed in this report[1].

		Lead based Technology		Alkaline Technology		Lithium-Ion	
		Pb 2020	Pb 2030	NiX 2020	NiX 2030	Lithium Ion 2020	Lithium-Ion 2030
Electrochemical -System	Cathode	PbO_2	PbO_2	β–NiOOH	β–NiOOH	NCM 111 (Gen.2a); NCM 523-622 (Gen.2b), LFP, LMO, LCO,NCA	NCM 622 –NCM811 (Gen.3a); NCM811, HE-NCM, HVS (Gen.3b); Solid State
	Anode	Pb, Pb+C	Pb, Pb+C	Cd, MH	Cd	LTO, C (Gen.2a, 2b)	C+ Si (5-10%) (Gen.3a); Si/C (Gen3b)
Energy Density [Wh/kg]	Cell	24 - 48	30 - 60	28 – 50	30 - 55	60 - 250	300 -450
	System	23 - 45	35 - 55	24 -43	38 - 50	20 - 140	80 - 400
Energy Density [Wh/l]	Cell	60 - 105	80 - 150	55 – 80	60 - 90	140 - 580	650 - 1100
	System	36 - 100	50 - 110	47 – 70	50 - 75	20 - 250	100 - 1000
Power Density [W/kg]	Cell	34 - 448	80 - 505	80 – 225	100 - 240	210 - 1800	450 - 1100
	System	41 - 400	65 - 450	68 – 180	80 - 210	170 - 520	250 - 700
Power Density [W/l]	Cell	91 - 880	120 - 920	112 – 400	120 - 460	470 - 2200	800 - 2500
	System	76 - 840	72 -900	95 – 350	100 - 380	180 - 650	600 -1200
Lifetime	FCE (Full Cycle equivalent)	200 - 2500	1000 – 4800	3000	4000	> 3500	>10.000
	Calendaric Lifetime [a]	10 - 25	10 - 25	20	20	10	15 - 25
Operation Temperature range [°]		- 25 - +50	- 25 - +50	- 50 - +60	- 50 - +60	0 … +45 °C charge -20 … +60 °C dischage -30 … +55 (LTO)	-30 … +60
Energy efficiency [%]		67 - 85	> 90	70 – 85	> 85	> 90	95
Recycling	Efficiency (% of average weight)	90	90	79	80 - 85	50	80 - 85

Fig. 2 Table of performance parameters for each battery technology – state-of-the-art in 2020 and targets for 2030

1 EUROBAT internal best estimates

4 Overview of the Key performance indicators (KPIs) for the innovation per technology

The spider diagrams hereunder give an overview of the state of play in 2020 and the innovation potential by 2030 of each battery technology with regard to the key battery performance indicators, such as gravimetric and volumetric energy and power densities, fast recharge time, energy throughput, calendar life and recycling rate.

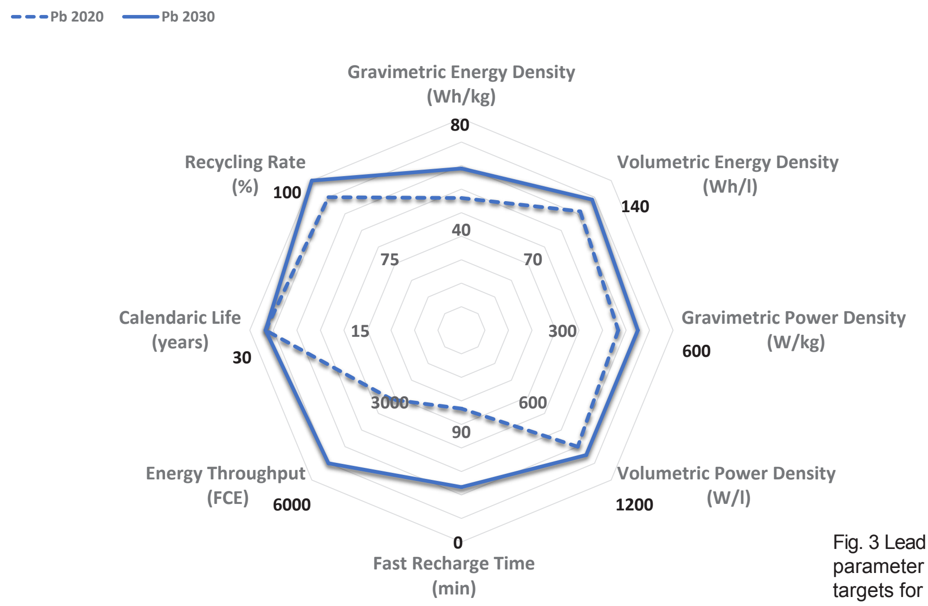


Fig. 3 Lead based technologies: key performance parameter data – state-of-the-art 2020 and targets for 2030

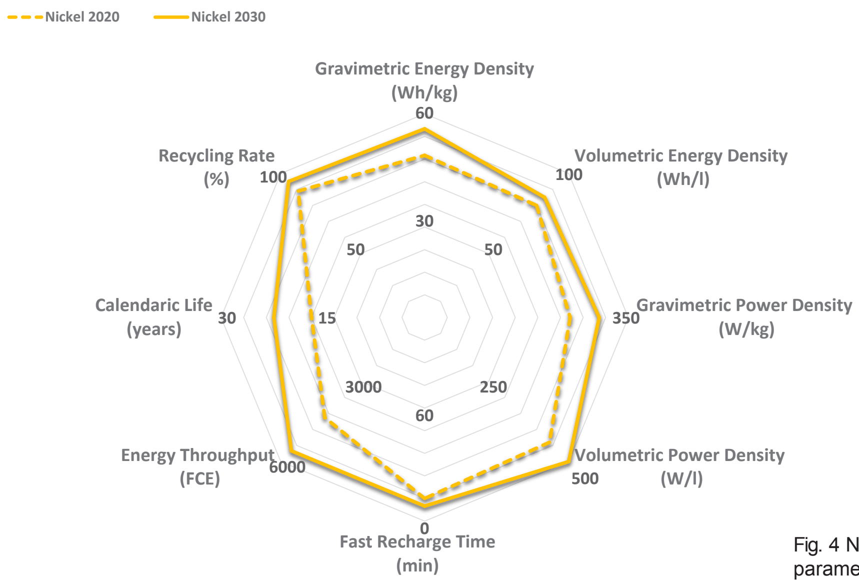


Fig. 4 Nickel based technologies: key performance parameter data – state-of-the-art 2020 and targets for 2030

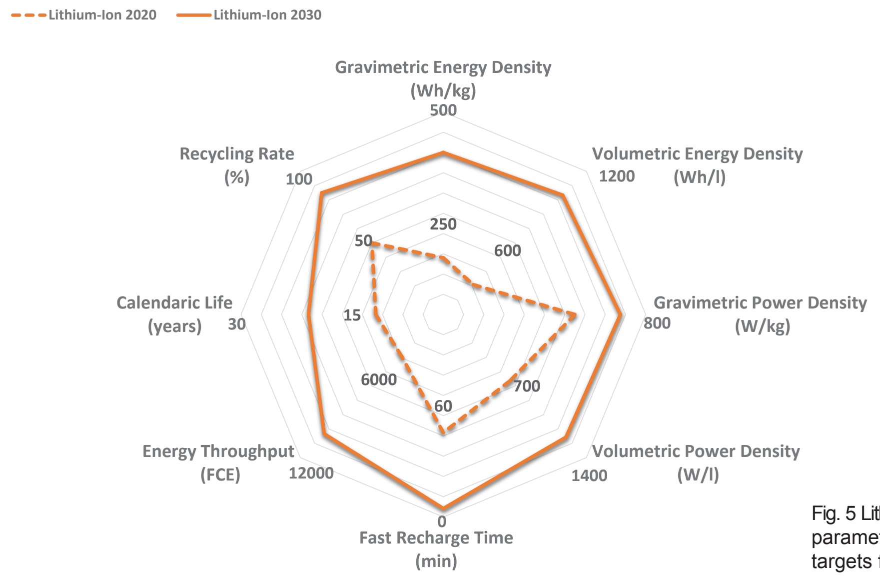


Fig. 5 Lithium based technologies: key performance parameter data – state-of-the-art 2020 and targets for 2030

Overview of the targeted key performance indicators by 2030 for each battery technology, demonstrating the continuation of the complementarity of the technologies in the market

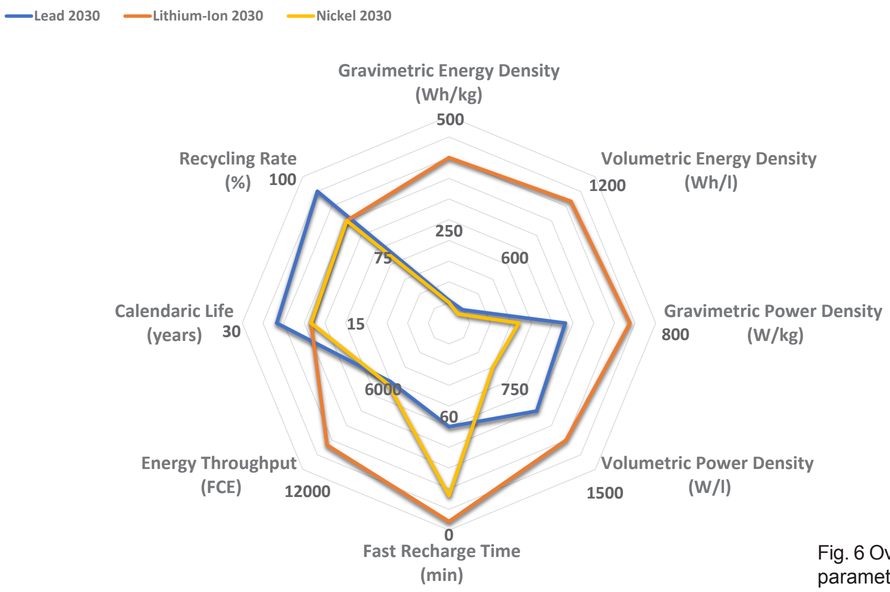


Fig. 6 Overview of the targeted key performance parameter data by 2030 for each technology

The technologies considered in this White Paper have different potential for further development depending on their technological maturity. However, for all the technologies considered, the optimisation of individual parameters has a direct impact on the other parameters. Thus, an improvement in one parameter can be accompanied by the decline of another. This makes it necessary to develop electrochemical storage technologies tailored to the requirements of a specific application.

This roadmap is focused on highlighting the innovations of each of the various chemistries, however, it should also be stressed that combining battery chemistries intelligently also provides synergies, such as in recent developments for mild-hybrid EVs or in BEVs where the HV lithium propulsion battery is supported by the LV advanced lead battery to ensure the functional safety.

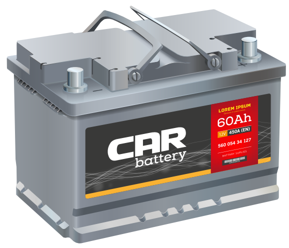
5 Mainstream battery technologies and KPIs per application

Area 1 Automotive Mobility

- **Auxiliary 12V batteries**
- **Start-Lighting-Ignition 12V batteries (SLI batteries)**
- **Heavy Commercial Vehicle Stand-by batteries (HCV Stand-by batteries)**
- **Battery Electric Vehicle propulsion batteries (BEV batteries)**

Auxiliary 12V batteries

Application profile:



The characteristic parameters for auxiliary automotive applications in all kinds of hybridisation, from micro HEV to full EV, are vibration endurance, energy density, long cycle life and high temperature life, as well as low temperature performance. Safety and recyclability are also key characteristics for these applications, while cost is also an issue for original equipment manufacturers.

Mainstream battery technologies and key performance indicators:

The dominant technology for this application today is lead, both flooded and AGM. Together with lead, lithium, mostly LFP, will also fulfil future requirements.

Key performance indicators for the innovation of automotive 12V auxiliary batteries are energy and power density, system cost, high temperature life, low temperature working conditions, cycling life and recycling efficiency.

High temperature life, low temperature performance, recycling efficiency and cost will continue to be advantageous for lead batteries in auxiliary applications, while cycle life and energy densities should be further improved.

Lithium batteries will be advantageous for parameters such as energy and power densities, and cycle life at ambient temperatures. Nevertheless, high cost, safety and recyclability, as well as extreme temperature performance, need to improve more than expected in order to become competitive with lead technologies. As the safety aspect for the auxiliary services is also crucial, lead will generally remain the preferred option, both flooded and AGM battery types. For lithium based batteries, LFP and LTO batteries will become the anode chemistry of choice for such applications.

European production capacities:

Annual European production for lead batteries is currently 2GWh and is forecast to reach 12GWh by 2030, assuming that lead will remain the dominant technology for auxiliary batteries

Start-Lighting-Ignition 12V batteries (SLI batteries)

Application profile:

Cranking a thermal engine within a wide ambient temperature range is the main feature of the 12V SLI battery, as well as providing energy to power the lights and other accessories in the car when the engine is not running, or when the engine is running but the energy demand is higher than the alternator can supply. Cranking the thermal engine and providing energy to multiple accessories when the engine is not running has become the major challenge to meet the ever increasing demands of the widespread start-stop micro hybrid architectures that are introduced in the original equipment market (OEMs).

Mainstream battery technologies and key performance indicators:

The dominant technology today is lead AGM and EFB. Together with lead, lithium will also fulfil the requirements in future. Both lead and lithium technologies will co-exist in this category in the future, although lead will remain the dominant technology for the next decade.

The successful introduction of start-stop micro hybrid architectures, which are becoming increasingly powerful with longer stops, for example when cutting the engine before the car stops, the requirements of this application are increased high cycle life and energy/power densities.

The key performance indicators for the innovation are increased vibration endurance, energy and power density, system cost, energy throughput, dynamic charge acceptance, operating temperature range and recycling rate.

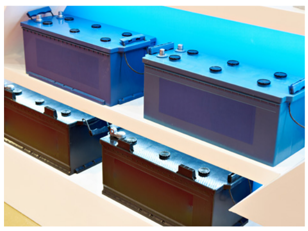
Opportunity charging to capture the kinetic energy of the car will be key to improving energy efficiency. High voltage and low voltage Li-ion systems are developing further, but lead can also support the capture of excess energy. Dynamic charge acceptance is a key innovation in such applications. The priority is to increase this dynamic charge acceptance fivefold to 2 Amps/Ah already by 2022 to meet market demand.

European production capacities:

Today's annual European production for lead batteries is 60GWh, which is forecast to reach 70GWh by 2030. Lithium, however, is 0.5GWh today and expected to reach 5 GWh by 2030.

Heavy Commercial Vehicle Stand-by batteries

Application profile:



When charging or discharging trucks in cities when the engine is turned off, a very high energy supply is needed to serve the heavy loads. This requires specifically designed high-energy batteries with deep-cycle performances.

Mainstream battery technologies and key performance indicators:

The dominant technology for this application is lead. Together with lead, lithium could also function in this category to cater for future requirements.

Key performance indicators for innovation are energy and power density, total cost of ownership, energy throughput, dynamic charge acceptance, vibration robustness and recycling rate.

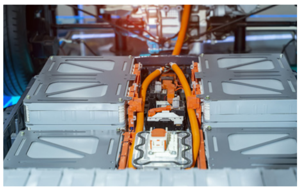
Deep-cycle lead batteries have the potential to improve through increasing the charge acceptance and decreasing the total cost of ownership. The current conventional starting or dual-purpose lead batteries cannot meet such deep-cycle performances. Today, only lead is in this new market, but in future lithium might also break through, although the temperature window and total cost of ownership will be challenges.

EU production capacities:

The annual production of lead batteries in Europe today is 10GWh, which is estimated to reach 18GWh by 2030.

Battery Electric Vehicle propulsion batteries (BEV batteries)

Application profile:



For EV applications, the emphasis is on strong power and high energy needs as longer ranges and faster charging are required. The environmental, safety and security aspects also play a crucial role for this application.

Mainstream battery technologies and key performance indicators:

The mainstream technology today is lithium NMC/LFP, while NMC and solid state technologies will be targeted for development by 2030.

Key performance indicators for innovation are energy and power density, system cost, energy throughput, charge acceptance, operating temperature range and recycling rate.

EV batteries, in particular, need faster charging regimes and to develop their energy application in order to extend the range. In this respect, the EV application requires material research in order to continue to increase the volumetric and gravimetric energy densities. Solid state technology will help to increase cell voltages and thus the energy content. At the same time, it will contribute to the security and safety aspects by preventing thermal runaway in the batteries, as a potential result of an accident or other high physical stress.
Recycling is 50% today, but with 2nd life and further research, we expect progress to be made by 2030.

EU production capacities:

Annual European production of EV lithium batteries today is between 5 and 15GWh and is estimated to reach 200-400GWh by 2030, depending on the market scenario used.

Area 2 | Material handling and logistic applications

- **Batteries for material handling**
- **Batteries for Automated Guided Vehicles and carts (AGV/AGC batteries)**

Batteries for material handling

Application profile:

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Material handling vehicles are used in warehousing and distribution for loading and unloading, handling pallets, and picking and storing inventory. For this reason, the application requires high power charge and discharge rates, high energy content, cycle life and operating times.

Mainstream battery technologies and key performance indicators:

The three mainstream technologies, lead, nickel and lithium are complementary and all have the potential for innovation in these applications. The general technical requirements for energy storage systems in material handling are high charge and discharge rates, high energy content, cycle life and operating times, high recyclability, low investment cost and the need to meet strict safety requirements. Other increasingly important requirements are high capacities (increased truck dynamics), namely the power density, high temperature performance and energy efficiency in particular for multiple shift operations with improved PSOC cycling or opportunity charging and need for low maintenance.
Lithium technologies face a number of issues, such as cost, safety and high mass energy density. R&D should focus on these features so that these batteries can penetrate the market.

Batteries for Automated Guided Vehicles/Carts (AGV/AGC)

Application profile:

The workload of AGVs and AGCs can vary considerably, depending on the application profile, but they are mostly heavy-duty because of high loads. Major requirements are exceptionally high cycling capability, particularly in partial state of charge (PSOC) operations, extremely low internal resistance, high power density, fast charging capability (15-20 minutes), high charge acceptance, low maintenance and mechanical and electrochemical stability.

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Mainstream battery technologies and key performance indicators:

Lead-based batteries still have the biggest market share today. The robust NiCd technology, originally the choice for AGV applications in harsh environmental conditions, will continue to keep its small but significant market share.

Lithium is also entering the market successfully to meet increased requirements in terms of autonomy, powering loads and limiting the cost of ownership. Therefore, energy and power density, as well as cyclability, need to be further improved to meet these challenges.

Area 3 | Off-road transportation

- Railway batteries
- Marine batteries

Railway batteries

Application profile:

New upcoming applications for battery systems are the **hybridisation and electrification of rail power traction**, mainly for commuter and metro trains, which require high energy, power density and cyclability.

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Mainstream battery technologies and key performance indicators:

The dominant technology is lead, both flooded and sealed, but nickel and lithium also have a significant share of the market.

The development trends for on-board units favour lithium. For the **hybridisation and electrification of rail power traction**, mainly for commuter and metro trains, the requisite high energy, power density and cyclability is clearly an advantage for lithium batteries, which also ensure maintenance-free and longer lifetime operations. **To power auxiliary functions**, as well as lights and fans in high speed and metro trains, the nickel-based chemistry is the preferred technology because it can function in rush operational conditions.

As for further developments in infrastructure, different battery technologies will co-exist given the variety of applications, including lead batteries, both flooded and sealed.

Due to development trends for on-board units with smaller footprints, weight restrictions and constant reliability needs, the future requirements for energy storage systems consist mainly of improvements to volumetric energy density, lifetime and operating temperature ranges.

Marine batteries

Application profile:

Smaller **battery electric boats**, such as canal, river and lake vessels, are boats propelled by mechanical systems consisting of an electric motor turning a propeller to reduce noise and operate with zero emissions. Battery electric boats are often integrated into a fleet of vessels which has an onshore charging infrastructure in place.

Mainstream battery technologies and key performance indicators:

The dominant technology today is lead, both flooded and sealed, but Lithium NMC is also breaking through in this market.

The market for small electric propelled vessels will increase considerably in future to meet demand. Due to high safety requirements for on-board system use with severe ventilation requirements, reduced need for maintenance, high vibration resistance and horizontal inclination aspects, we predict that both lead and lithium batteries will co-exist. Lead batteries will shift towards valve regulated technologies, both AGM and EFB, and lithium batteries towards NMC but also LFP due to safety reasons.

Key performance indicators for innovation are energy and power density, energy throughput, charge acceptance, operational temperature range and recycling rate.

Apart from R&D, further battery standardisation is an opportunity to increase reliability and safety, as well as to reduce the total cost of ownership.

Area 4 | Stationary Energy Storage Batteries

- **Uninterrupted Power Supply Batteries (UPS batteries)**
- **Telecom batteries**
- **Residential and Commercial Energy Storage Batteries behind the meter**
- **Utility grid-scale Energy Storage Batteries (ESS Batteries)**

Uninterrupted Power Supply Batteries (UPS Batteries)

Application profile:

UPS batteries provide instantaneous power to a system if the main power source fails. New requirements for these batteries are increased critical loads and additional functions, such as peak-shaving, as well as auxiliary services for double conversion and line-interactive systems.

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Mainstream battery technologies and key performance indicators:

The dominant technologies used today are lead, VRLA with absorbent glass mat and NiCd. Lithium is also entering the market with LFP, LMP and NMC with Carbon anodes by 2030 to target NMC with Carbon-Silicon anodes.

Increasing the power density is particularly necessary because of the further electrification of critical loads, which require greater output from the battery. Also, as new UPS batteries should provide additional value, such as peak-shaving, there is a need to work on the charge acceptance of the batteries.

The technology of choice is not only related to the type of load, but also depends on the climate (temperature robustness), quality of the grid, configuration of the UPS and energy throughput, while cost remains a key factor.

Key performance indicators for innovation are energy and power densities, system cost, energy throughput, charge acceptance, operational temperature range and recycling.

EU production capacities:

Today, annual European production of lead batteries is 2.4GWh, while lithium is forecast to rise from 0.05GWh to 0.5GWh by 2030.

Telecom batteries

Application profile:


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A telecom unit is an information and communication technology or telecom site with critical loads. In case of unavailability or insufficiency of the main power source, telecom batteries provide instant and continued DC voltage power to all redundant equipment to ensure that the telecom application continues to function.

Mainstream battery technologies and key performance indicators:

The dominant technology used today is lead VRLA absorbent glass mat for reliable grids and VRLA with gelled electrolyte (GEL) in weak grids. Lithium has a small but significant share in these markets, both LFP and NMC with carbon anodes to target NMC carbon-silicon anodes by 2030.

In contrast to UPS batteries, telecom batteries serve only telecom applications, connected to the 48V DC electricity supply net for an information and communication technology or telecom site. These batteries will take over the electricity supply in cases of unavailability or insufficiency of the main power source. As the battery is part of a double conversion system, an important driver is the demand for increased energy throughput, particularly because of the rolling out of 5G networks.

Key performance indicators for innovation are energy and power density, system cost, energy throughput, charge acceptance, operating temperature range and recyclability.

EU production capacities:

Annual European production of lead batteries today is 3GWh. Production of both lead and lithium is expected to increase by 2030.

Residential and commercial Energy Storage Batteries behind the meter

Application profile:

The primary task of these batteries is to supply the load when electricity cost is high or renewable power output too low. Drivers for residential and commercial storage are increased self-consumption and the need to ensure power continuity. Home storage batteries should be designed and sized according to the location and local power needs.

Mainstream battery technologies and key performance indicators:

The dominant technologies today are lithium-based, mostly NMC and LPF. Lead batteries – AGM/GEL – are less present in these markets but they might come back in future with advanced lead batteries to serve this market and compete with NMC solid state.

Both lead and lithium will compete in this market, each with their own features. Lithium has an advantage in terms of space, but safety can be an issue for in-house storage requirements, necessitating a move to solid state technology. For lead, bipolar technology will increase energy density and charge efficiencies.

Lead today is not only almost fully recyclable, but also has economies of scale in place that work without any subsidies. For lithium, there is still progress to be made for recycling to be economically viable by 2030. Design life needs to be improved for both technologies, as well as the cycle life.

The PSOC cycles of the batteries, according to the European reference test standards, should increase from 1,500 cycles to 2,500 by 2025.

Key performance indicators for innovation are the Battery Management System (BMS) requirements, design life, cycle life, high temperature operation, charge efficiency, energy density and economy of recycling.

Utility large grid-scale Energy Storage Batteries (ESS Batteries)

Application profile:

Large scale energy storage batteries cover a large variety of operational ranges, depending on the grid function it will fulfil. Hereunder is a tabulation including the application profiles for some key grid functions, such as voltage/frequency regulation, arbitrage, black-start, back-up, investment deferral and grid independent power supply (GIPS).

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	Segment	Power rate (MW)	Response time	Storage capacity	Charge acceptance	Cycles (#/year)	Efficiency (%)	Energy density	Condition of operation
Regulation	Conventional	1-40 MW	<1 min- 60min	0,5 - 20 MWh	Sec.	250-10 000		Low	
	PV		15-60min			250 – 1 000			
	Wind		<1 min-60min						
	End-users	0.1-10 kW	0,1-15min	na		10-200			
	T&D	na	<1 min-60min						
Arbitrage	Generation	0.1-500 MW	<1-6h	0.1->1GWh	Hours	50-250		Moderate	
	PV integration				Min.				
	Wind integration								
	Seasonal	10-1000 MW	2-8 h	> 50 MWh up to 10000 MWh	Hours	10-50			
	Residential	2 - 6 kW	1-6h	4 - 10 kWh	Min.	50-250			
	Commercial/ industrial	6 kW - 5 MW		12kWh - 10 MWh	Min.	250-500			
Black-start	Generation	5-50 MW	15-60min	5-50 MWh	Hours	10-20		Moderate	
	Industrial								
Back-up	Small – UPS	5 - 2000 kW	<1-60sec	3 - 1000 kWh	Hours	10-20		Moderate to high	
	Medium and large UPS	50 MW	1-60min	100 MWh	Hours				
	Power continuity	0.5 - 100 kW	0,25-6 h	0,5 - 200 kWh	Hours	5-100		Low	
	Reserves	1-500 MW	2-8 h	1 - 500 MWh	Hours	10-50			
Invest. Deferral	Transmission & Distribution	1-100 MW	1-4 h	2 - 200 MWh	Hours	50-100		Moderate	
GIPS	Community/rural	10-100 MW	2-8 h	40 - 400 MWh	Min.	50-500		Low	
	Residential	0,1-20 kW		1-50 kWh					
	Industrial	0.5 - 15 kW		2 - 50 kWh					

Fig. 7 Overview of application profiles for different grid functions, which batteries can fulfil

Key technical requirements for grid functions are reliability, safety, scalability of the power supply and low maintenance and service cost as well as the lifetime and the charging/discharging efficiency.

Mainstream battery technologies and key performance indicators:

For large storage systems, lithium and lead technologies are considered the reference technologies. Nickel-based batteries were previously preferred for large system storage in low temperature applications. Lithium is relevant for high-current applications like optimising self-consumption through the integration of renewables and peak-shaving (100kW–5MW). A distinction must be made between energy and power applications.

Drivers and trends for grid support applications are major infrastructure changes in the power supply industry, the integration of renewables, emerging electro-mobility and demand for higher power quality. **General technical requirements** are PSOC cyclability, high power density and wide operating temperature ranges. **Drivers and trends for off-grid applications** are increased demand for independent power supplies and reduced infrastructure costs. **General technical requirements are** high reliability, scalable power supply and low maintenance/service cost.

The development of the multi-use aspect will increase profitability for the user. Due to their multifunctional capabilities, storage systems are often efficiently used in the form of mixed operating models in which several areas of application are combined ("multi-use storage systems").

Advantages for lithium storage in non-automotive applications were first expected for peak-shaving applications. These advantages consist of a large potential market, low safety risks and a short amortisation time of around five years. Ten years ago, this application was driven by the higher cost of lithium cells. As the cost of lithium cells has fallen, the applications have been upgraded to the extent that lithium cells now compete with larger lead cells.

Other grid applications include frequency regulation, voltage support, black start, energy time shift and peak-shaving. A particular feature is the projected service life of 20 years, which lowers investment costs. A way of reducing costs for Li-ion systems for peak shaving and energy time shift for renewables is to deploy second-life EV batteries.

Research priorities for lead are cycle life, up to 6,000 cycles at 70% DOD, 2,500 PSOC cycles according to the European performance test standards, and charge efficiency higher than 95%, according to IEC standards, by 2025. Advanced large industrial VRLA lead batteries (with capacities up to 15 MWh) with carbon additives entered into service recently in Germany. Lead carbon batteries can match the PSOC cycle life of lithium batteries for voltage stabilisation in solar power plants.

Research priorities for lithium are safety, capacity, retention of the negative graphite electrodes and material cost reduction of the positive electrode, e.g. through reduced cobalt and higher nickel content.

Although lead batteries currently represent less than 2% of large utility grid-scale ESS, intelligently combining lead- and lithium-based batteries could increase the market significantly for lead as it would offer considerable benefits in terms of lower energy reserve costs. This could be achieved by installing lead-based and smaller lithium-based batteries for power peaks. Battery systems with strings of Li-ion batteries have already been considered in telecom applications. A lithium battery would deliver almost 100% of the load at the beginning, whereas a lead battery would take charge in the middle and final stages of discharge.

The Primary research priorities for lead is to increase the cycle life at 70% DOD from 1,000/3,000 cycles to 6,000 cycles by 2025 and 6,800 cycles by 2030, which is main economic indicator for energy storage applications.

Today, charge efficiency of AGM batteries, according to IEC standards, is 85-90% and is targeted to reach 95+% by 2030.

Key performance indicators for utility and renewable energy storage are lifetime, charging/discharging efficiency and safety. The research priority for lead up to 2030 is cycle life (up to 6,800 cycles at 70% DOD) in order to lower operating costs, and for lithium it is primarily safety.

The key battery performance indicators for innovation are safety, reliability, power and volumetric energy density, high and low operating temperatures, float life, cycle life and PSOC cycling.

Glossary

AGM: Absorbent Glass Mat; the difference with ‘flooded’ is that the electrolyte is held in glass mats
AGV: Automated Guided Vehicle
AGC: Automated Guided Carts
Batteries 2030+: EC initiative to bring research and industry together to develop next generation batteries
BatteRIes Europe: European Technology and Innovation platform for R&D on Batteries
Battery cyclability: The number of times that a battery can be recharged at a given DOD
BEV: Battery Electric Vehicle
BMS: Battery Management System
DC: Direct Current
DOD: Depth of Discharge
DSO: Distribution System Operators
EBA: European Battery Alliance
EFB: Enhanced Flooded Batteries. Flooded means ‘wet’, filled with a mixture of acid and water
ERRAC: The European Rail Research Advisory Council.
ESS: Energy Storage System
ETIP SNET: European Technology and Innovation Platform Smart Networks for Energy Transition
EV: Electric Vehicle
FLOODED: Or ‘wet’ means it operates by means of a liquid electrolyte solution
GEL: A VRLA battery with a gelified electrolyte in which the sulphuric acid is mixed with fumed silica, which makes the resulting mass gel-like and immobile
GIPS: Grid Independent Power Supply
ICE: Internal Combustion Engine
HCV: Heavy Commercial Vehicle
HEV: Hybrid Electric Vehicle
HV: High voltage
LFP: Lithium iron phosphate
LTO: Lithium titanate oxide, a type of modified lithium battery which uses lithium-titanate nanocrystals, instead of carbon on the surface of its anode
LV: Low Voltage
NMC: Nickel Manganese Cobalt Oxide, a type of lithium battery made of several materials common in other lithium-ion batteries, involving a cathode combination of nickel, manganese and cobalt.
PSOC: Partial State of Charge
PHEV: Plug-in Hybrid Electric Vehicle
SLI: Start-Lighting-Ignition
TTPL: Thin Plate Pure Lead AGM design
TSO: Transmission System Operators
UPS: Uninterrupted Power Supply
UPSaaR: UPS as a reserve power
Vehicle on-board net: the on-board 12V DC system to power different loads
VPP: Virtual Power Plant
VRLA: Valve Regulated Lead Acid
WLTC: Worldwide Harmonised Light Duty Vehicles Test Procedure: https://dieselnet.com/standards/cycles/index.php#eu

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